CLEAN WATER

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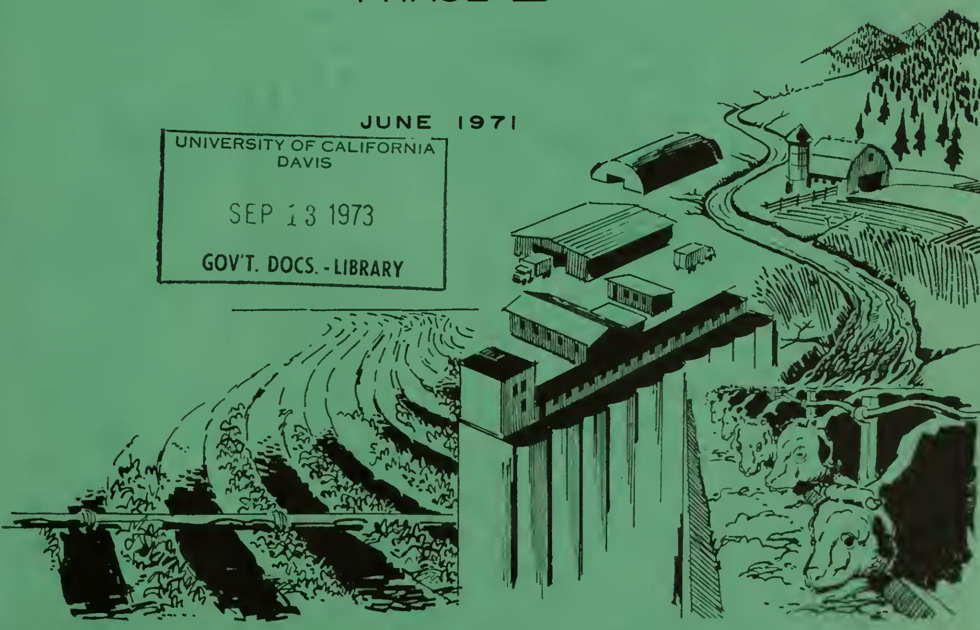
BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE

SAN JOAQUIN VALLEY, CALIFORNIA

DENITRIFICATION BY ANAEROBIC FILTERS AND PONDS

PHASE II

JUNE 1971



VIRONMENTAL PROTECTION AGENCY•RESEARCH AND MONITORING

BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE SAN JOAQUIN VALLEY, CALIFORNIA

The Bio-Engineering Aspects of Agricultural Drainage reports describe the results of a unique interagency study of the occurrence of nitrogen and nitrogen removal treatment of subsurface agricultural wastewaters of the San Joaquin Valley, California.

The three principal agencies involved in the study are the Water Quality Office of the Environmental Protection Agency, the United States Bureau of Reclamation, and the California Department of Water Resources.

Inquiries pertaining to the Bio-Engineering Aspects of Agricultural Drainage reports should be directed to the author agency, but may be directed to any one of the three principal agencies.

THE REPORTS

The first, three-year phase of the interagency study is to be reported upon in a series of twelve reports.

The second, one-year phase of the interagency study was limited to continued work on the two principal treatment methods. The second phase work develops design criteria and operational parameters for full-scale treatment facilities.

This report, "DENITRIFICATION BY ANAEROBIC FILTERS AND PONDS -- PHASE II", and the companion report, "REMOVAL OF NITRATE BY AN ALGAL SYSTEM -- PHASE II", contain the results of the second phase of the interagency study. These two reports are numbered sequentially, after the first twelve, in the series entitled "Bio-Engineering Aspects of Agricultural Drainage, San Joaquin Valley, California".

DENITRIFICATION

BY

ANAEROBIC FILTERS AND PONDS

PHASE II

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REVIEW NOTICE

This report has been reviewed by the Water Quality Office of the Environmental Protection Agency, U. S. Bureau of Reclamation, and the California Department of Water Resources and has been approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the reviewing agencies nor does mention of trade names or commercial products constitute endorsement or recommendation for use by either of the reviewing agencies.

ABSTRACT

Operational criteria, design and operating costs for a treatment facility to remove nitrogen from agricultural tile drainage in the San Joaquin Valley were further investigated during 1970 at the Interagency Agricultural Wastewater Treatment Center (IAWTC) near Firebaugh, California. The year-long study is identified as Phase II. Based on projected nitrate-nitrogen concentrations for valley tile drainage water, the research in this phase extended earlier Phase I studies on the feasibility of bacterial denitrification by filters and covered ponds. The anaerobic filter with 1-inch rounded aggregate was capable of reducing influent nitrate-nitrogen from 30 mg/l to 2 mg/l at water temperatures from 12° to 16°C at a 6-hour detention time, and from 15 mg/l to 2 mg/l at water temperatures of 20° to 24°C at 1-hour detention time. Long-term operation of filters resulted in accumulation of bacterial mass which caused the deterioration of the hydraulic regime and nitrogen removal efficiencies. Air scour accompanied or followed by flushing with water was capable of controlling the bacterial mass. The consumptive ratio, a method to quantify the organic carbon source needed for the anaerobic bacterial process, was affected by temperature and influent nitrogen concentration and was found to vary between approximately 1.2 and 2.4. The anaerobic covered pond reduced influent nitrate-nitrogen from 30 mg/l to 2 mg/l at water temperatures of 12° to 16°C with a 60-day detention time and from 15 mg/l to 2 mg/l at 20° to 24°C with a 10-day detention time.

This report is submitted in partial fulfillment of Project No. 13030 ELY under the sponsorship of the Environmental Protection Agency.

BACKGROUND

This report is one of a series which presents the findings of intensive interagency investigations of practical means to control the nitrate concentration in subsurface agricultural wastewater prior to its discharge into other water. The primary participants in the program are the Environmental Protection Agency, the United States Bureau of Reclamation, and the California Department of Water Resources, but several other agencies also are cooperating in the program. These three agencies initiated the program because they are responsible for providing a system for disposing of subsurface agricultural wastewater from the San Joaquin Valley of California and protecting water quality in California's water bodies. Other agencies cooperated in the program by providing particular knowledge pertaining to specific parts of the overall task.

The ultimate need to provide subsurface drainage for large areas of agricultural land in the western and southern San Joaquin Valley has been recognized for some time. In 1954, the Bureau of Reclamation included a drain in its feasibility report of the San Luis Unit. In 1957, the California Department of Water Resources initiated an investigation to assess the extent of salinity and high groundwater problem and to develop plans for drainage and export facilities. The Burns-Porter Act, in 1960, authorized San Joaquin Valley drainage facilities as a part of the California Water Plan.

The authorizing legislation for the San Luis Unit of the Bureau of Reclamation's Central Valley Project, Public Law 86-488, passed in June 1960, included drainage facilities to serve project lands. This Act required that the Secretary of Interior either provide for constructing the San Luis Drain to the Delta or receive satisfactory assurance that the State of California would provide a master drain for the San Joaquin Valley that would adequately serve the San Luis Unit.

Investigations by the Bureau of Reclamation and the Department of Water Resources revealed that serious drainage problems already exist and that areas requiring subsurface drainage would probably exceed 1,000,000 acres by the year 2020. Disposal of the drainage into the Sacramento-San Joaquin Delta near Antioch, California, was found to be the least costly alternative plan.

Preliminary data indicated the drainage water would be relatively high in nitrogen. The Environmental Protection Agency conducted a study to determine the effect of discharging such drainage water on the quality of water in the San Francisco Bay and Delta. Upon completion of this study in 1967, the Agency's report concluded that the nitrogen content of untreated drainage waters could have significant adverse effects upon the fish and recreation values of the receiving waters. The report recommended a three-year research program to establish the economic feasibility of nitrate-nitrogen removal.

As a consequence, the three agencies formed the Interagency Agricultural Wastewater Study Group and developed a three-year cooperative research program which assigned specific areas of responsibility to each of the agencies. The scope of the investigation included an inventory of nitrogen conditions in the potential drainage areas, possible control of nitrates at the source, prediction of drainage quality, changes in nitrogen in transit and methods of nitrogen removal from drain waters, including biological-chemical processes and desalination.

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SECTION I

SUMMARY AND CONCLUSIONS

Anaerobic Denitrification

Bacterial denitrification in anaerobic filters and anaerobic covered ponds is a feasible means of removing to a level of 2 mg/l or less as total nitrogen, the nitrates that vary seasonally between 14 mg/l and 34 mg/l from agricultural tile drainage in the San Joaquin Valley. This finding, demonstrated earlier in Phase I of the investigation, was further supported by research resulting from Phase II. Moreover, data collected during Phase II showed that no operational problems would impair the successful treatment of the waste by these methods. Cost estimates as developed in Phase I of $92 per million gallons for anaerobic filters and $88 per million gallons for covered ponds are still considered applicable.

Anaerobic Filters

1. The most feasible medium in terms of nitrogen removal efficiency cost was 1.0-inch diameter rounded aggregate.

2. Experimental work over extended periods of operation with 1.0-inch rounded aggregate indicated that filters will produce an effluent which meets the criterion of 2 mg/l of total nitrogen. The anaerobic filter was capable of reducing influent nitrate-nitrogen from 30 mg/l to 2 mg/l at water temperatures from 12° to 16°C at a 6-hour detention time and from 15 mg/l to 2 mg/l at water temperatures of 20° to 24°C at a 1-hour detention time. Detention times of 1 to 6 hours were required during the remainder of the year as the water temperature varied from 16° to 20°C and the influent nitrate-nitrogen varied from 15 to 30 mg/l.

3. Long-term operation necessitated the removal of bacterial mass from the medium beds of the filters. Air injection of air at 10 scfm/ft^2 for 5 to 30 minutes with or followed by flushing with water was the most promising method tested.

4. The consumptive ratio for anaerobic filters, which determines the quantity of required organic source, varies with water temperature and influent nitrogen concentration. At 12° to 16°C, the ratio varies from about 1.5 to 2.4, while at 20° to 24°C the ratio varies from about 1.2 to 2.0.

Anaerobic Covered Ponds

1. The anaerobic covered pond was capable of reducing influent nitrate-nitrogen from 30 mg/1 to 2 mg/1 at water temperatures from 12° to 16°C at a 60-day detention time and from 15 mg/1 to 2 mg/1 at water temperatures of 20° to 24°C at a 10-day detention time. During the remainder of the year as the influent nitrate-nitrogen varied from 15 to 30 mg/1 and the water temperature varied from 16° to 20°C, detention times between 10 and 60 days were required.

2. Recirculation of 25 percent of the effluent was necessary to give the results presented in Item 1 for most of the year. However, when the water temperature is above 20°C, the recirculation appears unnecessary.

SECTION II

INTRODUCTION

This report covers the Phase II experimental studies on bacterial denitrification of San Joaquin Valley agricultural tile drainage waters at the Interagency Agricultural Wastewater Treatment Center (IAWTC) near Firebaugh, California. Phase I of the studies, which ended in December 1969 was devoted to determining whether or not the processes under study were technically feasible methods for removal of nitrate-nitrogen from agricultural tile drainage. The purpose of Phase II was to develop operational criteria and to substantiate treatment cost estimates.
This report presents only new information obtained during Phase II, the 1970 calendar year. The reader should refer to the Phase I report Denitrification By Anaerobic Filters and Ponds (1) for literature review, description of units, and Phase I results and conclusions.

SECTION III

METHODS AND MATERIALS

The description and methods of operation for the anaerobic denitrification units used in Phase II studies were essentially unchanged from those described in the Phase I report (1). When pertinent, minor modifications in unit design and operations are described in the "Results and Discussion' of this report. A summary of sampling frequency and methods of analysis is presented in Table 1.

Phase I results, except for several cases, were obtained using a constant influent nitrate-nitrogen concentration of 20 mg/1. For Phase II studies, in order to approximate conditions expected in a treatment plant for San Joaquin Valley tile drainage, the influent nitrate-nitrogen concentration was adjusted to conform to the predicted tile drainage flow as presented in Figure 1 (2).

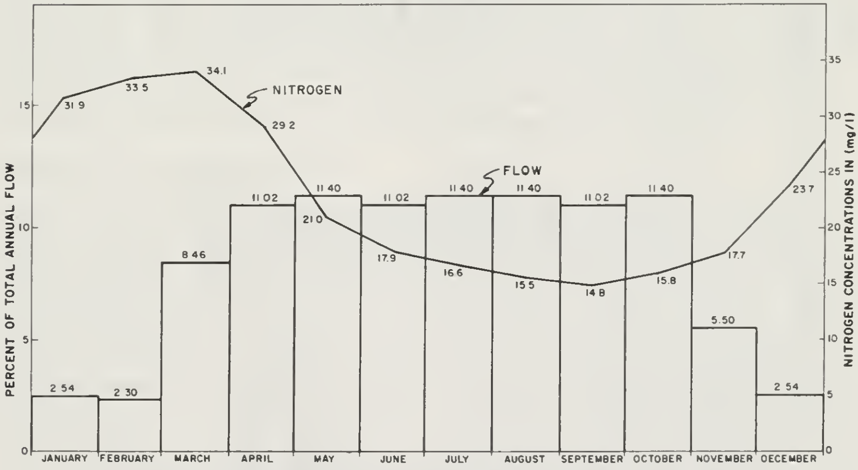

FIGURE 1 - PREDICTED DRAINAGE FLOW AND NITRATE-NITROGEN CONCENTRATION FOR TILE DRAINAGE

TABLE 1

SUMMARY OF SAMPLING FREQUENCY AND METHODS OF ANALYSIS

PARAMETERS	FREQUENCY FILTERS	FREQUENCY PONDS	METHODS
Nitrate-Nitrogen	6-12/week	3/week	Specific Ion Electrode and Modified Brucine
Nitrite-Nitrogen	6-12/week	3/week	Diazotization, Standard Methods 12th Edition
Total Kjeldahl Nitrogen	2-4/month	2-4/month	Kjeldahl Method
Ammonia Nitrogen	1-2/month	1-2/month	Distillation Method
Organic Nitrogen	1-2/month	1-2/month	Kjeldahl Method
Orthophosphate	1/month	1/month	Modified Stannous Chloride
pH	1/week	1/week	pH Meter Glass Electrode
Alkalinity	1/month	1/month	Titration, Standard Methods
Dissolved Oxygen	Daily	Daily	Winkler Method, Azide Modification
Suspended Solids	1/week	1/week	GFA Glass Paper, 103°C
Volatile Suspended Solids	1/week	1/week	GFA Glass Paper, 560-580°C
Methanol	3/week	3/week	Gas Chromatograph, Carbowax Column
Electrical Conductivity	1/month	1/month	Conductivity Cell, Standard Methods 12th Edition
Chlorides	as needed		Silver Nitrate Titration, Standard Methods, 12th Edition
Rhodamine B Dye		as needed	Fluorometric Determination

SECTION IV

RESULTS AND DISCUSSION

The primary objectives of Phase II prepilot scale studies to be discussed in this report were to: (1) determine the effect of extended operation on treatment efficiency, (2) further define the relationship of detention time and temperature to nitrogen removal, (3) determine the effect of periodic flushing of filters on nitrogen removal rate and hydraulic regime, (4) determine the effect of seasonal variation of influent nitrate-nitrogen, (5) refine preliminary cost estimates for treatment facilities, and (6) refine design criteria for pilot plant facilities. The Phase I results indicated uncovered ponds would not meet required nitrogen removal efficiencies and studies were discontinued.

Anaerobic Denitrification Filters

Field evaluation of anaerobic denitrification filters was initiated in October 1967 using 4-inch diameter PVC filters. Use of these small filters was subsequently discontinued and the 18-inch diameter and 36-inch diameter filters were constructed to study start-up procedures, temperature effects, nitrogen loading, long-term operation and filter media. In May 1969, a pilot-scale unit 10 feet square and 6 feet deep was built to study the effect of increased unit size and to further study effects of temperature and long-term operation. Phase II studies involved use of the 18-inch diameter and the pilot-scale units. The medium used was one-inch rounded aggregate with the exception of one unit which utilized artificial medium. Unless otherwise noted, this discussion refers to units with the aggregate medium.

Temperature and Detention Time

Temperature changes, length of hydraulic detention time, and influent nitrogen concentrations are major interrelated variables which affect nitrate-nitrogen removal in anaerobic filters. As the temperature decreased or the influent nitrogen concentration increased, longer detention times were required to meet an effluent total nitrogen criterion of 2 mg/l. In Phase I studies, it was demonstrated that when water temperatures were in the range of 14° to 20°C a 1-hour detention time was necessary to reduce an influent nitrate-nitrogen concentration of 20 mg/l to 2 mg/l total nitrogen. When the water temperature dropped to 12° to 14°C, a 2-hour detention was required to produce the same water quality. In Phase II, the temperature-detention time relationship was more complicated because the influent nitrate-nitrogen concentration was varied to approximate concentrations expected in tile drainage.

Figure 2 illustrates the effect of detention time on nitrogen removal throughout the year. In March when temperatures were approximately 14° to 16°C and the influent nitrate-nitrogen concentration was approximately 34 mg/l, a detention time of one hour will result in an effluent

total nitrogen of about 22 mg/l, while the detention time would have to increase to 6 hours to produce an effluent of 2 mg/l. In August, with temperatures of 24° to 26°C and an influent nitrate-nitrogen of 14 mg/l, a one-hour or longer detention time produced effluent containing a total nitrogen concentration of 2 mg/l. The curves shown in Figure 2 are considered conservative in their depiction of removal efficiency because they are based on averages which fluctuated daily. For example, although in August the effluent nitrogen averaged 2.9 mg/l with the detention time at one-half hour, in a significant number of instances the nitrogen concentration was as low as 1.1 to 1.5 mg/l at this detention time. With better operational control, such as methanol injection and its dispersion in the wastewater, the predicted detention time requirement may be significantly reduced. In addition, the data were based on the theoretical detention time and not on actual detention time. The actual detention was less than the theoretical detention time due to reduced void volume caused by excessive bacterial mass as shown in a latter section of this report.

An artificial medium, Koch FLEXIRINGS, was installed in an 18-inch diameter filter in order to evaluate their effectiveness. The filter was placed into operation in February 1970, however, consistent nitrogen removal did not develop until June. A summary of results is presented in Table 2. At water temperatures of 20° to 22°C, influent nitrate-nitrogen concentrations of about 15 mg/l were reduced to less than 2 mg/l total nitrogen at a 3-hour detention time. However, with

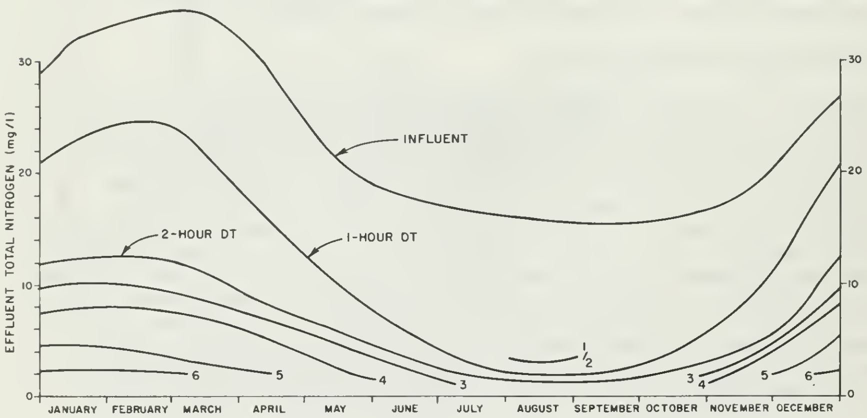

FIGURE 2 - PREDICTED ANNUAL EFFECT OF DETENTION TIME ON TOTAL EFFLUENT NITROGEN IN AGRICULTURAL TILE DRAINAGE

TABLE 2

NITRATE-NITROGEN REMOVAL
ARTIFICIAL MEDIUM FILTER

DETENTION TIME (hrs)	TEMPERATURE °C	TOTAL INFLUENT NITROGEN (mg/l)	EFFLUENT	
			NITRATE + NITRITE (mg/l)	TOTAL NITROGEN (mg/l)
4	22-24	12.53	1.77	2.35
4	24-26	14.69	.19	0.83
3	22-24	14.60	.53	1.13
3	24-26	12.41	.20	0.90
3	20-22	15.42	1.08	1.82
3	20-22	20.51	5.51	5.86
3	18-22	21.81	3.84	4.19
6	16-18	23.08	8.60	9.23
6	14-16	22.41	8.68	9.44
8	12-14	20.44	4.85	5.76
8	10-12	20.44	7.84	8.98

water temperatures between 18° to 22°C and an influent nitrate-nitrogen concentration of about 22 mg/l, an effluent of 4.19 mg/l was produced at a 3-hour detention time. At 10° to 12°C and an influent nitrate-nitrogen concentration of 20 mg/l, an effluent of 8.98 mg/l total nitrogen was produced at an 8-hour detention time. The reason for the extended period required to obtain the desired nitrogen reduction is not completely understood, although it most likely was due to the low water temperatures when first started. The physical characteristics, such as the configuration and surface of the medium may have effected the bacterial buildup. In general, the detention times required for denitrification were about twice as long as were required with the use of 1-inch aggregate filters. However, because the void volume is 96 percent for the artificial medium compared to about 40 percent for 1-inch aggregate medium or about 2.4 times greater, the actual hydraulic loading and nitrogen loading on the two media were comparable.

Organic Nitrogen and Ammonia

Concentrations of organic nitrogen and ammonia in the anaerobic filter effluent are related to nitrogen loading and temperature. A portion of the bacterial growth will be washed from the filter and the remaining bacteria will eventually decompose and organic nitrogen and ammonia will be released. In addition, any algae growth or suspended material occurring in the drainage will be retained in the filter. Decomposition of this material will increase organic nitrogen and ammonia in the effluent. It has been shown that with the influent at an assumed nitrate-nitrogen concentration of 20 mg/l, the nitrogen would be assimilated and the production of cellular biomass would be 12.1 mg/l (1). Effluent volatile solids normally range from 2 to 6 mg/l indicating a buildup of organic matter within the filter. This organic matter decomposes and is then removed in the effluent as ammonia. The effluent from filters operated for less than one year normally varies seasonally from 0.8 to 1.5 mg/l total Kjeldahl nitrogen. The effluent ammonia normally ranged from 0.1 to 0.4 mg/l ammonia-nitrogen or about 25 percent of the total Kjeldahl nitrogen. The effluent from filters that were allowed to operate without being disturbed for more than one year had effluent Kjeldahl-nitrogen concentrations of up to 2.0 or 2.5 mg/l. The increase which occurred at the higher water temperatures was due almost entirely to increased ammonia-nitrogen from bacterial decomposition.

Flushing the filters to physically disrupt the bacteria resulted in an increase in total Kjeldahl-nitrogen for a period of 10 to 40 detention times following the disruption. This short-term increase in nitrogen was in the organic form and varied from 0.5 mg/l to 3.0 mg/l. Effluent from units flushed at regular or irregular intervals were not characterized by the higher ammonia-nitrogen concentrations experienced during warmer temperature periods.

Organic Carbon Source

An organic carbon source is necessary for the dissimilatory nitrate-nitrogen reduction process. Methanol was the source selected for the Interagency Agricultural Wastewater Treatment Center. McCarty (3) evaluated acetic acid, ethanol, acetone and methanol as organic carbon sources. He found acetic acid to be the most efficient but also the most expensive of those tried. Methanol and acetone were the least expensive, with overall results favoring the use of methanol.

The consumptive ratio is defined as one obtained by dividing the actual quantity of organic carbon source required to denitrify and deoxygenate a waste plus the carbon required for cell growth by the stoichiometric requirement for denitrification and deoxygenation of the waste (1). It is used to quantify the carbon source needed to complete the denitrification process. The original assumption for the consumptive ratio in the denitrification of tile drainage with methanol as the carbon source was 1.3. Phase I studies found that the actual ratio was 1.47, with a standard

deviation of $\pm .36$. This was based on a constant influent nitrate-nitrogen concentration of 20 mg/l. With variable nitrate-nitrogen concentration and temperature, the consumptive ratio varied as indicated in Figure 3. At water temperatures between 18° and 24°C, the consumptive ratio for an influent nitrate-nitrogen concentration of 25 mg/l was about 1.2, while at 15 mg/l, it was about 2.0. At temperatures below 16°C, the increase in the consumptive ratio may be from 25 to 50 percent. The seasonal variation in influent nitrate-nitrogen concentration and the methanol concentrations required to denitrify the influent are shown in Figure 4. The values for the consumptive ratio are generally higher than expected for the denitrification process. These higher than normal values may have resulted when excess methanol in the system was consumed through methane fermentation and thus not detected in the effluent. Calculations of required methanol concentration were based on the assumption that dissolved oxygen concentrations averaged 8.0 mg/l. This finding may not be valid when drain waters are treated because algae growth in the drainage canal may cause the water to contain a higher level of dissolved oxygen.

The results of a study on the response of denitrifying bacteria to changes in methanol addition are summarized in Figure 5. A filter operated on a 1.5-hour theoretical detention time (65 minutes actual detention time) was used to measure the effect of eliminating methanol injection for approximately 4 detention periods and then returning the filter to normal operation. The nitrate-nitrogen concentration of the

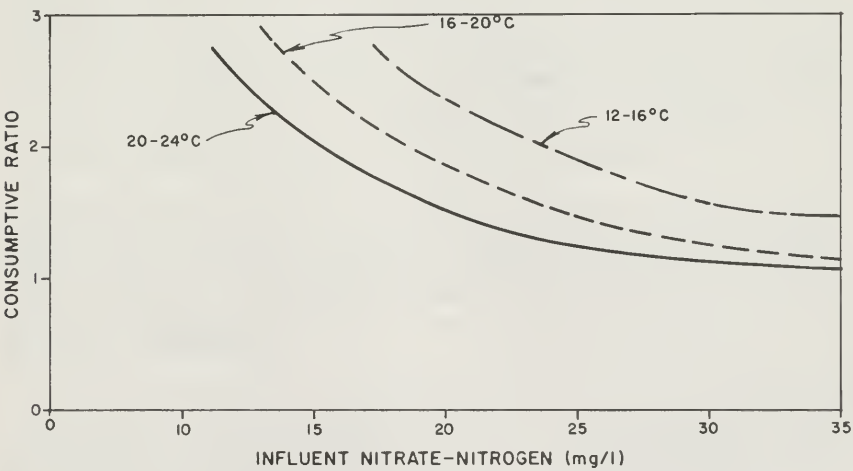

FIGURE 3 - CONSUMPTIVE RATIO AT DIFFERENT INFLUENT NITROGEN CONCENTRATIONS AND TEMPERATURES

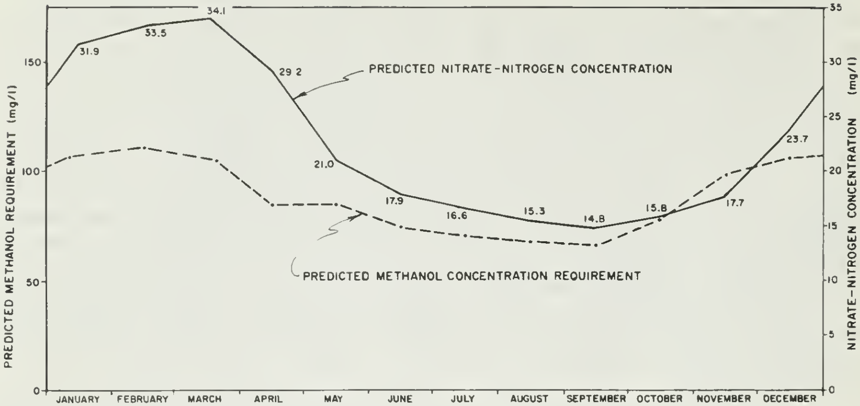

FIGURE 4 - SEASONAL VARIATION IN REQUIRED METHANOL INJECTION AND INFLUENT NITRATE-NITROGEN CONCENTRATION

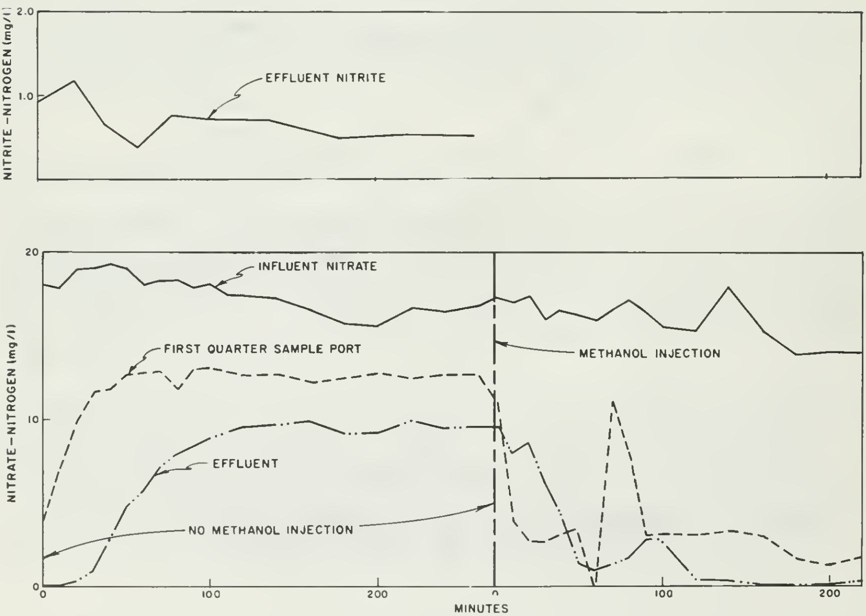

FIGURE 5 - NITRATE-NITROGEN REMOVAL RESPONSE TO METHANOL INJECTION IN ANAEROBIC FILTERS

influent to the filter was about 18 mg/l, the initial effluent nitrate-nitrogen concentration was essentially zero, and the water temperature was 22°C. Within minutes after turning off the methanol, a decrease in nitrogen removal was evident at the first quarter-point sample port. The decline became progressively evident throughout the filter. After one detention time the effluent nitrate-nitrogen concentration stabilized at about 9.5 mg/l and remained at that concentration until the end of four detention periods. The return to normal methanol injection resulted in a return to zero nitrate-nitrogen in the effluent within one detention period. The fact that about 60 percent of the influent nitrogen was removed when the methanol supply to the filters was stopped indicated that the denitrification process can still proceed for a period after the organic carbon source injection is terminated. The continuation of this dissimilatory process may be related to the endogenous respiration of the bacteria. Another possibility is that the denitrification was brought about in conjunction with the decay of bacteria.

Biomass Control

Short-term operation of anaerobic filters in Phase I studies indicated that 1-inch diameter aggregate was a more suitable medium than was gravel or sand because it was not readily plugged by bacterial cells. However, if filters containing 1-inch aggregate were operated continuously for more than one year, bacterial growth did significantly affect the nitrogen removal efficiency. Increased total Kjeldahl-nitrogen in the effluent, increased required influent pressure, and short-circuiting through the filter indicated a significant bacterial buildup. Methods which might kill the entire bacterial population, such as enzymes or toxic materials, were not considered in that it was desirable to leave a healthy seed to restart the unit. In Phase II, the problem of biomass removal was solved by a systematic program designed to stabilize the active bacterial population and maintain a constant usable void volume. The method selected was one in which the filters were physically disturbed but normal long-term filter operation was not disrupted.

The bacterial mass in the 18-inch filters was shaken loose with the use of air injection for regular 15-minute periods at a rate of 0.6 standard cubic feet per minute per square foot (scfm/ft^2). The biomass was then drained or flushed at intervals of 300, 600 or 1200 detention times. Tracer studies were made before and after each flushing operation to study the hydraulic regime. The filters were started and run for 8 months with the interval flushings.

In analyzing the hydraulic tracer studies of the three flushing filters, no definite conclusions can be made on the effect of the method used or of the length of intervals between flushing. There were instances when the hydraulic regime was definitely improved by removing a significant amount of bacterial growth. On the other hand there were instances when the hydraulics were impaired by a reduced plug flow and usable void volume. In these cases it was assumed the bacterial mass was disturbed

by the scour but not sufficiently removed from the filter by the flush. In Phase I studies, operational problems due to accumulated bacterial mass did not become noticeable until one year of continuous operation was concluded. At least one year's operation appears necessary to identify any significant results in nitrogen removal from flushing at regular intervals.

Required pressure of influent water is directly related to an increase in plugging by an accumulated mass of bacteria. Figure 6 indicated that this pressure will be reduced by interval flushing. The filters showed an immediate reduction in required influent pressure after flushing followed by a rapid recovery during the next approximately 100 detention times which in turn was followed by a leveling off of pressure.

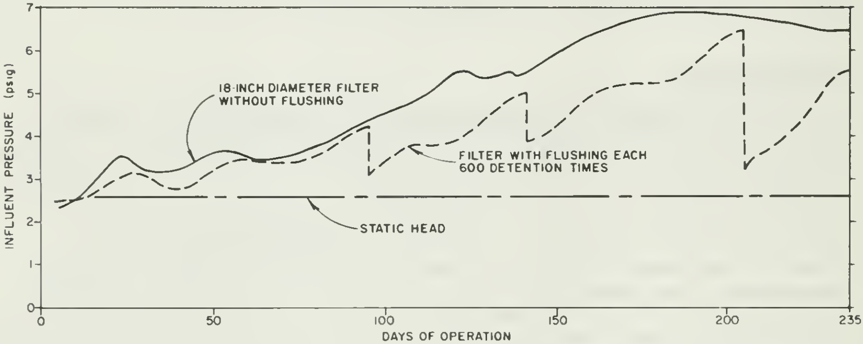

FIGURE 6-REQUIRED INFLUENT WATER PRESSURE TO FILTERS WITH INTERVAL FLUSHING

There was a general increase of required pressure associated with long-term operation. After 235 days of operation, the filter flushed at 600 detention intervals was operating at pressures of 1 to 2 psi less than the unit not flushed. Interval flushing at 1200 detention times did not cause the reduction in pressures except for short periods following the flushing.

With the exception of the recovery period after flushing, no significant change in nitrogen removal efficiency was noted between filters. The recovery period, as shown in Figure 7 with representative examples, varied from several days at temperatures of 18° to 24°C to about two to four weeks at temperatures below 18°C. The restarting process usually involved increasing the detention time to four times as long as that in normal operation, and then reducing it in stages when satisfactory nitrate-nitrogen removal efficiency had again been attained. There were several occasions when the detention time was not varied from the operating detention and

the filter regained acceptable nitrogen removals within reasonable time periods. During the 235 day period no difference was noted in total Kjeldahl nitrogen for filters operated the same length of time and either not flushed or flushed at intervals. As stated in the Phase I report, long-term operation without disturbing the filter can result in increases of ammonia-nitrogen up to 2.5 mg/l at the higher temperatures. If the unit had been flushed, effluent ammonia-nitrogen concentrations were rarely above 0.2 or 0.3 mg/l during the summer months.

The pilot-scale filter unit was flushed several times in the fall between days 529 and 555 in response to the deterioration of the hydraulics caused by accumulation of biomass. This unit had last been flushed in March at day 311. Several rates of air injection were tried along with either draining the filter or increasing the water flow through the unit. The initial air injection was 0.5 scfm/ft^2 and increased in several stages to 10 scfm/ft^2. Between each air injection and flushing the filter was operated at least 5 days to evaluate pressures and hydraulic regime. By observation, 10 scfm/ft^2 of air applied in diffusers spaced 5 feet on center was required to thoroughly scour the medium. Large masses of bacteria were forced to the top of the unit and removed by water flowing through the unit. It was also observed that the smooth sidewalls of the filter unit allowed significant amounts of water or air to flow unrestricted up the sides. The overall effect would be reduced as unit size increased and would probably be remedied by incorporating a roughly textured surface or a system of baffles.

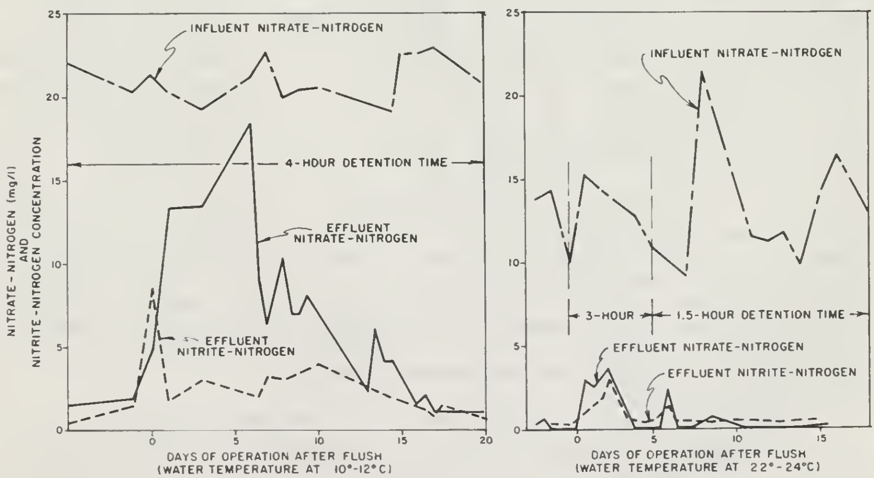

FIGURE 7 - FILTER RECOVERY AFTER BACTERIAL REMOVAL AT INTERVALS

In Figure 8 are plotted results of tracer studies performed on the pilot-scale filter which indicate the effect of biomass buildup and flushing. The analyses for days 311 and 406 bracket the flushing of day 318, while those on days 537 and 563 bracket the flushing on day 555. In each case the curve was shifted to the right of the preceding curve, which indicated a decrease in stagnant or plugged void volume and improved hydraulics of the unit resulting from the flushing. However, the gradual shift to the left shown by the curves for days 161, 406, and 563 indicates a gradual increase in plugging not completely removed by vigorous flushing methods.

Due to seasonal variations of San Joaquin tile drainage and climatic conditions, the greatest demand for treatment units is in the spring, while during the summer and into the fall the demand is down resulting in a reduction of filter units needed. Rather than having frequent scheduled flushings, the filter units might annually be taken out of service for several months at the slack period. At this time, a program of removing all or a large part of the bacterial mass could be used and the units could then be restarted during the period of warmer water temperatures.

Scale-up Factors

The major unknowns in the treatment of tile drainage by the anaerobic filters at this time are the problems to be encountered in the operation of a full-scale treatment unit. Such units may have a surface area of about 40,000 square feet or nearly one acre. Data on the units tested at the Interagency Agricultural Wastewater Treatment Center show that a major problem in operating a full-scale plant will be to maintain the desired hydraulic characteristics within the filter. If this problem could be solved, then the nitrogen removal efficiencies and required detention times determined by the pilot-scale studies could be extrapolated to a full-scale treatment facility. The anaerobic denitrification process itself is not affected by the size of the unit. Extensive profiles of units of the various sizes indicate no differences in the manner in which the nitrate is reduced to nitrites and then to gaseous nitrogen.

The pattern of accumulation of bacterial mass at the bottom of the filter with the greatest nitrogen removal in this area is not altered in the larger unit. In the larger units, even though they contain undoubtedly larger stagnant areas in which decomposition may occur, ammonia-nitrogen concentration (an indicator of bacterial decomposition) indicates no difference between the performance of the various sized units. There is no significant difference between the concentrations in the effluent of total Kjeldahl nitrogen or of suspended and volatile solids of the effluents from different size units.

The main problem in the operation of the large-scale anaerobic filters will be in maintaining a desirable hydraulic regime within the unit. Because of the confined volume of the smaller unit and the characteristics of the bacterial growth, required influent pressures become less as the

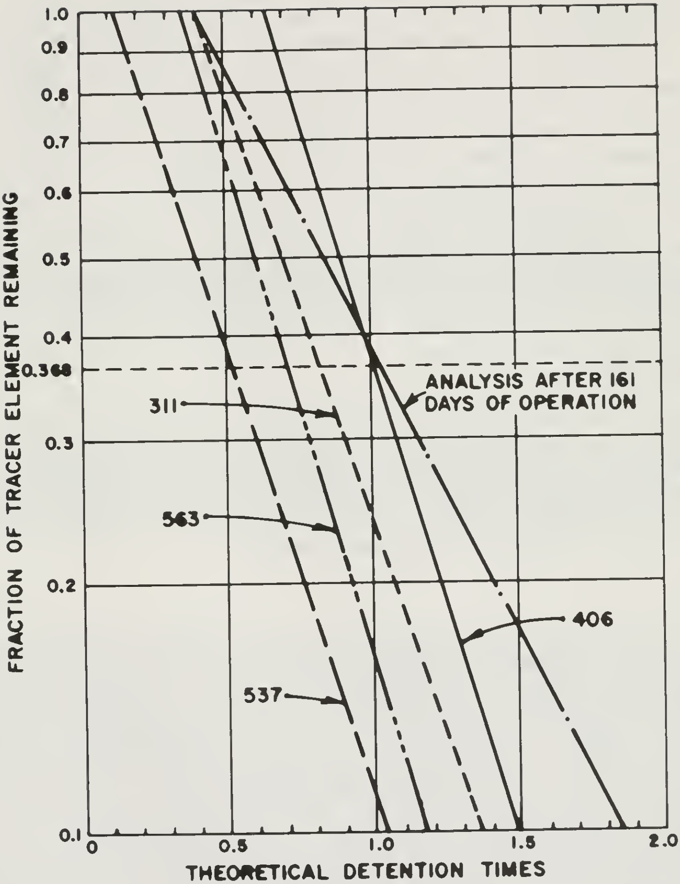

FIGURE 8-RESULTS OF HYDRAULIC TRACER STUDIES PERFORMED ON PILOT SCALE FILTER

unit size increases. In the larger units the required pressure probably would not exceed 6 pounds per square inch even if the unit were only flushed annually. The lower required operational pressure was verified in the pilot-scale unit. With less confinement or control of the flow through the filter, more short-circuiting or following of paths of least resistances took place.

The elimination of short-circuiting will depend on the ability to control or remove the bacterial masses. As described in the section on biomass control, air scrubbing, in conjunction with or followed by flushing with water, now appears to be the best method to remove excess biomass. With the larger units this process becomes more difficult. In the 18-inch diameter unit with its confining side walls, it appears about 0.5 to 1.0 $scfm/ft^2$ of air appears to be sufficient to break the bacteria loose from the medium. However, in the pilot-scale unit, about 10 $scfm/ft^2$ of air was necessary to give an even flow distribution. The air was injected in the diffusers located about 5 feet on center in the pilot-size unit. In a larger unit it might be necessary to decrease the distance between the diffusers or increase the air injection rate. The larger exposed area of the pilot-scale unit necessitated a greater input of air per unit volume of filter than needed in the smaller unit because of their closely confined exposed area. It should be noted that the pilot-scale unit was not regularly flushed. It was approximately 2800 detention times between flushing.

Study of larger units points to operational advantages of artificial medium over aggregate. At this time the high cost of artificial media would eliminate it from consideration. However, with more detailed studies on the artificial medium than were conducted at the Interagency Agricultural Wastewater Treatment Center, operational controls could be refined to bring it more in line with aggregate medium.

Phosphorus

Based on the empirical chemical formulation of $C_5H_7O_2N$ for bacterial cells, the nitrogen requirement is about 12 percent of the biological solids produced. The phosphorus requirement of facultative bacteria is reported to be about 2 percent of the solids weight (5). Thus if 12.1 mg/l of biological growth is produced at an influent concentration of 20 mg/l nitrate-nitrogen (1), then about 1.1 mg/l of nitrate-nitrogen and 0.24 mg/l of phosphorus are assimilated in the growth process. The theoretical ratio of required phosphorus to the influent total nitrogen, 1 to 84, is plotted in Figure 9 along with actual influent phosphorus. The influent phosphorus averaged about 0.09 mg/l, ranging from 0.0 mg/l to .19 mg/l and was only 10 to 30 percent of the theoretical required phosphorus. Effluent phosphorus normally ranged from 0.0 mg/l to 0.05 mg/l, with a major portion of the concentrations approximating 0.0 mg/l. Actual phosphorus consumption averaged about 0.08 mg/l, which is significantly less than the estimated requirement. It is entirely possible that the bacteria were lacking phosphorus for their assimilatory processes. However, the filters were capable of denitrifying all the nitrate-nitrogen present, which indicates

FIGURE 9 - THEORETICAL PHOSPHOROUS CONCENTRATION REQUIREMENT AND ACTUAL INFLUENT PHOSPHOROUS CONCENTRATION FOR FACULTATIVE BACTERIA

that the bacteria were able to function without the theoretical phosphorus requirement. A possible source of phosphorus may be recycled from decomposing bacteria. The limiting effect of low phosphorus concentration may have masked the effect of some other parameter such as temperature or detention time.

Filter Media

A primary objective of Phase I was to determine under field conditions the best medium for anaerobic denitrification filters. Media evaluated included activated carbon, sand, rounded aggregate, angular bituminous coal, volcanic cinders, and Dow SURFPAC. The texture and the sorptive quality of the medium surface did not appreciably affect removal efficiencies. In addition, no significant difference was noted in comparing efficiencies of filters containing media less than one inch in diameter and 1-inch diameter media. When operated for more than several months, these small-media units were plagued with poor hydraulics and pressure buildups that adversely affected efficiency. Aggregate media with diameters greater than one inch apparently did not have enough surface area to support a sufficient bacterial population. Dow SURFPAC, because of its open design did not allow sufficient bacterial mass to accumulate (1). Phase II research concentrated on filters with 1-inch aggregate. Several units were operated continuously from Phase I to give information on long-term operations. Other filters started during the year were used mainly to provide additional data on operations.

Early results from Phase I indicated that 1-inch aggregate medium would be best mainly because bacterial plugging did not occur as had been the case with small media. With long-term operation, i.e., longer than 12 months, bacterial plugging did occur to the detriment of the filter efficiency. As indicated in Figure 10, after 17 months of continuous operation with the 18-inch filter at 2 hours detention time, approximately 34 percent of the filter volume was stagnant. With 23 months of operation, 60 percent was stagnant. The stagnant zones appeared to increase each month from 2 to 2.5 percent of the total void volume.

With the progressive increase in volume of stagnant zones, the hydraulics of the unit deteriorated as was indicated by an increased mixed flow, a decreased plug flow, and drop in filter efficiency. Filter back pressure gradually built up to approximately 11 psi; however, pressures did not appear to be the problem that they were in media less than one-inch in diameter, where pressures exceeded 70 psig for the activated carbon medium and 30 psig in sand medium.

Two artificial media, Dow SURFPAC and Koch FLEXIRINGS, were selected for evaluation because their surface area and void volume were greater than those in the aggregate media (Table 3). Due to the larger void volume, the SURFPAC and the FLEXIRINGS required detention time at least two to eight times longer than did the 1-inch aggregate medium for the same level of nitrogen removed. The reason for the slower nitrogen removal was the larger void volumes in relation to effective surface area. The open design of the SURFPAC did not allow bacterial growth to accumulate sufficiently because of sloughing that occurred. At 16-hours detention

TABLE 3

CHARACTERISTICS OF FILTER MEDIA

MEDIUM	SURFACE AREA (ft^2/ft^3)	VOID VOLUME (ft^3/ft^3)
1-inch aggregate	6.7	.40
2-inch aggregate	8.7	.40
Koch FLEXIRINGS, 1-inch	65.0	.96
Dow SURFPAC	26.5	.94

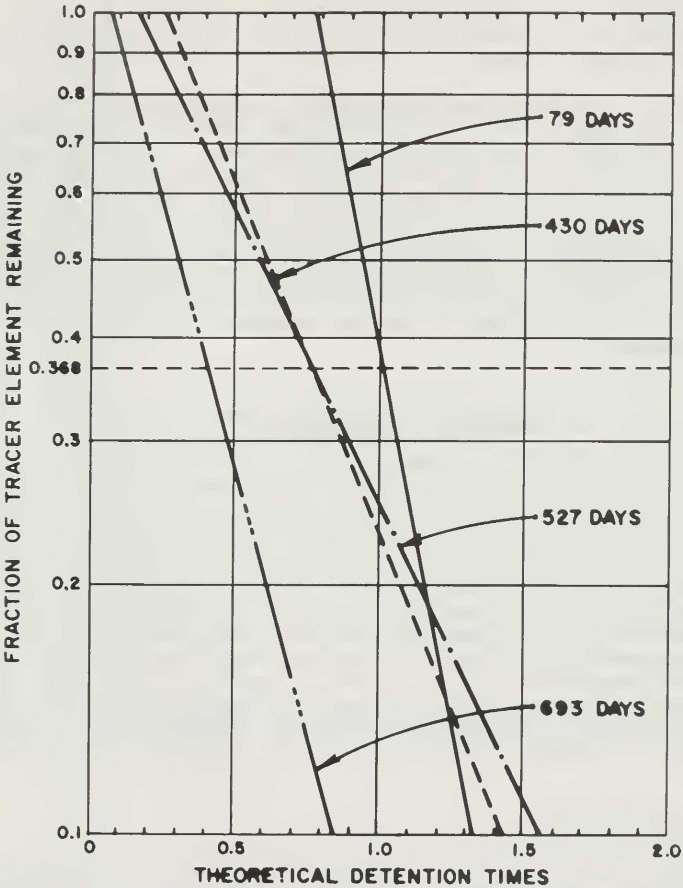

FIGURE 10. HYDRAULIC TRACER RESULTS FOR THE 2-HOUR DETENTION FILTER

time and a loading rate of 2.4 gal/ft^2/hr, the SURFPAC removed about 86 percent of the influent nitrogen compared to removal rates averaging 94 percent with the use of 1-inch aggregate medium at a 2-hour detention and a hydraulic loading of 8.6 gal/ft^2/hr. The FLEXIRINGS had a surface area of 65 ft^2/ft^3 as compared to 26.5 ft^2/ft^3 for SURFPAC. In addition, the design of the FLEXIRINGS eliminated the direct flow-through experienced in the SURFPAC. Within the 20° to 24°C temperature range, at a 3-hour detention time and a loading rate of 12.6 gal/ft^2/hr, the FLEXIRINGS removed 91 percent of the influent nitrogen. At the same water temperature a 1.5-hour detention and 11.9 gal/ft^2/hr loading rate, the 1-inch aggregate removed 90 percent of the influent nitrogen.

The start-up of the FLEXIRINGS filter with inoculum from another filter took about 120 days before consistently high nitrate-nitrogen removal rates were obtained at the shorter detention times. This was considerably longer than was the case when the filters containing aggregate media were used. The long start-up may have been due to the fact that the smooth surface of the PVC material may have failed to provide a good surface for bacterial attachment. About 150 days elapsed before any significant increase in influent pressure was observed. The pressure then gradually increased, but did not exceed 6 psig during the 400 days of operation. The increase in pressure coincided with an improvement in nitrogen removal.

Anaerobic Covered Deep Pond

Field evaluation of anaerobic denitrification in large-scale ponds was begun in September 1968 during Phase I. This research indicated that the deep covered pond with a 15-day detention time could meet the effluent criteria of 2 mg/l total nitrogen when water temperatures were between 14°C and 22°C. Uncovered deep ponds were eliminated from further study because the difficulty of maintaining anaerobic conditions prevented them from meeting the effluent criteria. In Phase II, the covered pond was evaluated with the objective of refining operational procedures and determining removal efficiencies at various detention times when the temperatures were below 14°C. A further objective of the Phase II pond denitrification studies was to maintain the effluent total nitrogen at 2 mg/l or less by adjusting the hydraulic detention time to allow for changes in nitrogen loading and prevailing or anticipated environmental conditions.

Summary of Operation

The covered pond was placed on a continuously mixed flow-through operation with a 20-day detention time in March 1969. The detention time was progressively lowered to 15-day, 10-day and finally to a 7.5-day detention period to match the water temperature increase during summer months and the maintenance of the effluent total nitrogen at 2 mg/l or less. At the 7.5-day detention time, the average effluent total nitrogen increased to approximately 4 mg/l. During the fall the detention time was lengthened

TABLE 4

SUMMARY

OPERATION AND EFFLUENT NITROGEN CONCENTRATION FOR THE COVERED DEEP POND

DAYS OF OPERATION	THEORETICAL HYDRAULIC DETENTION (day)	WATER TEMP. (°C)	AVERAGE INFLUENT NITRATE-NITROGEN (mg/1)	AVERAGE EFFLUENT NITROGEN CONCENTRATION			REMARKS
				NITRATE-NITRITE (mg/1) *	TOTAL NITROGEN (mg/1) *	TOTAL NITROGEN REMOVED (%)	
0-27	20	14-16	20	1.05	2.00	90	
28-39	15	14-16	20	0.51	1.96	90	
40-62	15	16-18	20	0.35	1.42	92	
63-97	15	18-20	20	1.08	2.58	87	
98-124	15	20-22	20	.54	1.80	91	
125-166 and 187-197	10	20-22	20	.29	1.49	92	
167-186	7.5	20-22	20	2.48	3.79	86	
198-218	10	18-20	20	1.39	2.57	92	
219-249	10	16-18	20	3.03	4.19	79	
250-260	10	14-16	20	2.44	3.73	82	
261-268	10	12-14	20	6.83	7.79	61	
270-281	15	12-14	20	(7.5)	(9.0)	55	End Phase I
281-315	20	10-12	32	17.42	17.10	47	Begin Phase II
315-345	33.5	12-14	31	3.08	4.52	85	
345-417	20	12-14	33	3.86	5.26	84	
417-440		14-18	--	--	--		No flow thru operation
440-469	15	18-20	16	(.2)	(1.5)	91	
469-501	10	20-22	14	.27	1.17	87	
501-547	10	20-22	12	(.2)	(1.5)	87	No recirculation
548-564	10	20-22	14	(.2)	(1.5)	89	
564-589	15	20-22	25	.99	2.24	91	No recirculation days 580 to 589
589-602	30	20-22	25	3.47	4.49	82	
602-618	30	18-20	27	5.72	6.9	71	
618-646	48	14-18	24	3.29	4.44	82	
646-705	60	10-12	31.5	4.0	5.1	84	
705-715	45	12-14	26.9	0.8	2.2	92	
715-736	30	12-14	35	(0.4)	(1.6)	93	

* Numbers in parenthesis are approximate

to 10 days and eventually to 15 days as the water temperature fell below 18°C. Throughout the winter months the effluent criterion of 2 mg/l was not met, although there were indications that it could be met at longer detentions. Low water temperatures prevented the pond from regaining the desired removal efficiency at a 33-day detention until March. Through 1970, the detention time was adjusted to maintain effluent nitrogen at 2 mg/l or less, while the influent nitrate-nitrogen was varied to approximate predicted tile drain flows.

Effect of Temperature and Detention Time on Nitrogen Removal

Nitrogen removal efficiency in covered ponds is affected mainly by temperature and detention time. Because most of the bacterial cells are not retained in the system, much longer detention times are required to produce a sufficient bacterial mass. To meet the effluent criterion throughout the year, detention times ranging from 8.9 days to 60 days were required. The relationship between effluent nitrogen, temperature, and detention time in covered ponds is indicated by the data presented in Table 4. Nitrogen effluents of less than 2 mg/l were obtained at 18°C to 22°C and a detention time of 10 days. During the cooler months, when the water temperatures were below 18°C and influent nitrogen concentrations were 25 to 35 mg/l, the average effluent nitrogen concentration ranged from 2 to 5 mg/l. However, at the lower water temperatures, nitrogen removal was up to 30 mg/l as compared to 10 to 12 mg/l during times when the water temperatures were warmer. Influent nitrogen loading in pounds per 1000 cubic feet of pond ranged from 0.03 pound per day at 48 days detention to 0.10 pounds per day at 10 days detention.

Nitrate-nitrogen and organic nitrogen were the major components of the total nitrogen present in the covered pond effluent. Nitrite-nitrogen concentrations were normally less than 0.5 mg/l. Total Kjeldahl nitrogen, which normally varied between 1.0 mg/l and 2.0 mg/l, was predominately organic in nature, with little or no ammonia-nitrogen. The absence of ammonia-nitrogen in the effluent indicated that the bacterial growth was being washed out of the unit before significant decomposition could occur.

Moore and Schroeder (6) stated the rate of nitrite reduction is slower than that of nitrate and showed that in a mixed system with continuous flow, nitrite will not accumulate and will be less than the nitrate concentration. This was verified in Phase I and II, as nitrite was essentially absent in the covered pond effluent when the nitrogen removal efficiency was high. In the instances where the level nitrite-nitrogen reached 2 to 10 mg/l, operational problems generally had occurred.

As noted earlier, the nitrogen concentration and flow rates from the tile drainage will vary seasonally. Fortunately, the longer required detention times will coincide with the low flows and the shorter detention times with the higher flows. Figure 11 presents the predicted detention times in covered ponds required for denitrification of agricultural tile drainage from the San Joaquin Valley at the various nitrate-nitrogen concentrations to be encountered.

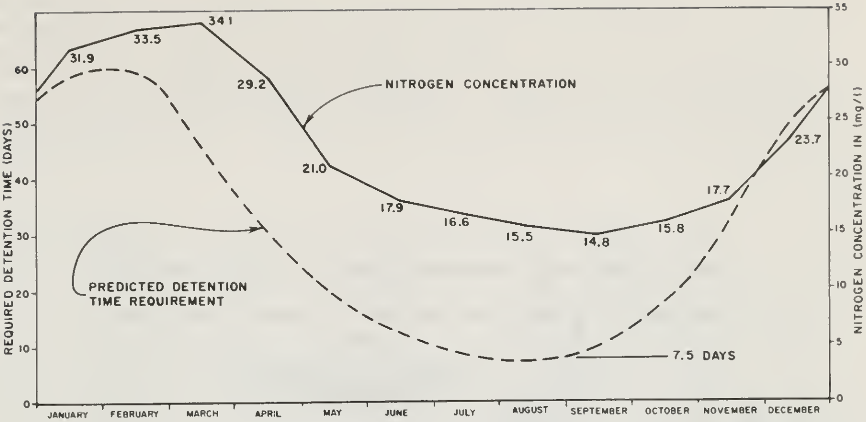

FIGURE 11- PREDICTED DETENTION TIME REQUIREMENT FOR COVERED POND TO MEET EFFLUENT 2-mg/l NITROGEN CRITERION AND TILE DRAIN NITROGEN CONCENTRATION

Hydraulic Studies

Temperature, fluorescence, and nitrate-nitrite profiles indicated that the covered pond was normally a completely mixed system. In Figure 12 are presented results of hydraulic tracer studies completed on the day 140, day 183, and day 548 which verified this observation. The tracer response curve for a theoretical 10-day detention time with recirculation shows the pond to be 82 percent completely mixed and 18 percent of the pond considered to be stagnant. About 4 percent of the flow through the pond was short-circuited. The actual detention time as indicated by the response curve was 8.2 days.

When the pond was operated on a 7.5-day theoretical (5.3-day actual) detention time with recirculation a tracer response study indicated a definite change in the flow pattern. A cross-section of the pond showed the dye stratified in a mixing pattern that was 27 percent plug flow, 44 percent completely mixed, and 24 percent stagnant zones. No short circuiting was noted.

A final tracer study was made when the pond was on a 8.9-day theoretical (8.1-day actual) detention time with no recirculation. The mixing pattern was identified as 18 percent plug flow, 73 percent completely mixed, and 9 percent stagnant zones. The pond had been without the recirculation for approximately three detention times before the study began. No indication of stratification in the pond or of short-circuiting was noted.

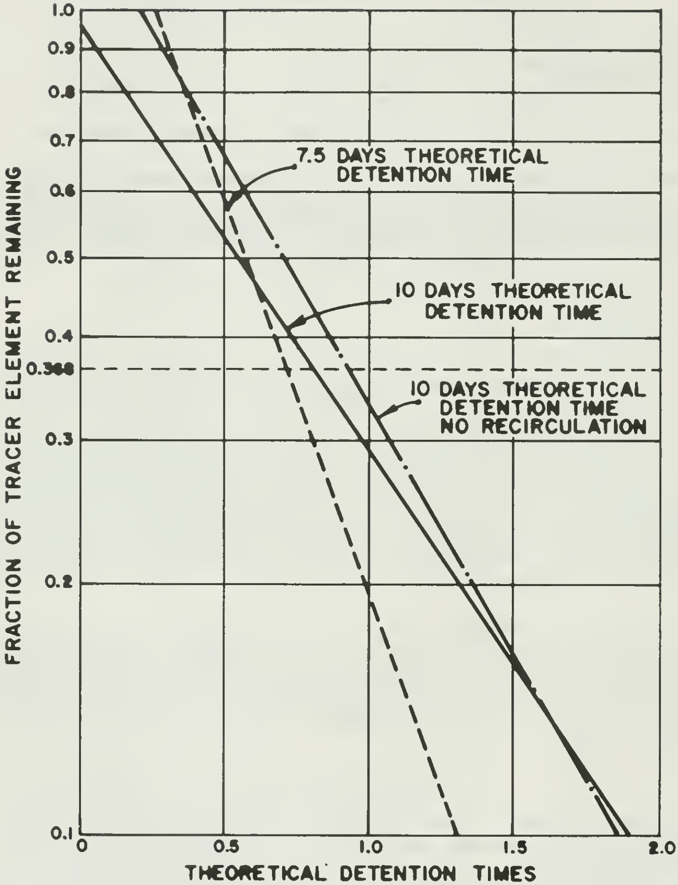

FIGURE 12. HYDRAULIC TRACER RESULTS FOR THE COVERED DEEP POND

The hydraulic tracer studies, along with occasional temperature profiles and weekly nitrate, nitrite and solids profiles, indicate that the pond was normally an almost completely mixed system. There were instances in which distinct stratifications appeared in the nitrate-nitrite on temperature profiles which suggest plug flow. These cases of stratification may have been caused by temperature differences between the pond and influent waters.

Recirculation

Because of the small amount of cell production which occurs during bacterial denitrification, recirculation of a portion of the total flow was used to seed the influent to the covered pond with active bacterial mass. If recirculation were eliminated, a reduction in capital cost for pumps and operation cost could be realized. With the exception of a short period during late summer, recirculation was used in the covered pond. At that time, the effluent total nitrogen was about 1.2 mg/l with nitrate-nitrogen and nitrite-nitrogen essentially zero. On day 501 of operation, with water temperatures at about 22.5°C and the detention time at 8.9 days, recirculation was withheld for about six detention times. No significant change was noted in the effluent nitrate, nitrite, or total Kjeldahl nitrogen for several detention times. Nitrate-nitrogen increased slightly at the influent end of the pond but at the middle of the pond this had fallen to zero. However, as the water temperature in the pond dropped below 21°C, the effluent nitrate-nitrogen plus nitrite-nitrogen increased slowly to 1.5 mg/l and total nitrogen rose to 2.7 mg/l. At this time, the recirculation was restored. Following resumption, the effluent nitrate-nitrogen showed decrease to about 0.5 mg/l within 10 days.

At a time when the water temperature was about 18°C and the pond was on a 15-day detention time, the recirculation pump was not operational for about 10 days. During this time the total effluent nitrogen jumped from about 2 mg/l to 5.5 mg/l. When the pump was restarted, the nitrate profiles of the pond showed a reduction in nitrates within several days, and within 10 days the effluent total nitrogen was down to 2.5 mg/l.

It appears that denitrification can be achieved with the necessary efficiency without recirculation if the detention period is sufficiently long. Because essentially no nitrates or nitrites occurred in the effluent when recirculation was suspended at the 8.9 day detention, a shorter detention with recirculation might have been sufficient. During cold water temperature periods, with a much slower growth rate of the bacteria, a much longer detention time without recirculation would undoubtedly be needed as opposed to the approximate 60 days needed with recirculation.

Recommended Design and Cost Estimates

Results of Phase II indicate that only minor changes should be made in the design criteria and operations of anaerobic filters and ponds as presented in the Phase I report. These changes did not justify a reevaluation of the cost estimates. Cost estimates from Phase I indicate that denitrification by a plant operated at full capacity would cost $92 per million gallons for anaerobic filters and $88 per million gallons for covered ponds. The preliminary cost estimates were considered conservative and refinement of these estimates would most likely reduce the expected treatment costs. Cost reductions of 20 to 25 percent might be realized by designing a treatment system with a capability to store the tile drainage during seasonally high flows and provide treatment when higher water temperatures permit higher loadings to the units.

The changes in design and operational criteria for the anaerobic filter are due to changes in biomass removal procedures. The filter box wall height would be reduced from 14 feet to 6 feet because it was felt that the extra hydraulic head was not necessary in the flushing operation. A more extensive air injection system is needed with the full-size unit divided into modules of approximately 40 feet square. No changes are suggested for design and operational criteria of denitrification in covered ponds.

SECTION V

ACKNOWLEDGMENTS

Phase II of the field investigations concerned with bacterial denitrification of tile drainage was performed under the joint direction of Messrs. Donald G. Swain, Sanitary Engineer, U. S. Bureau of Reclamation; Bryan R. Sword, Sanitary Engineer, Environmental Protection Agency; and Douglas L. Walker, Civil Engineer, California Department of Water Resources.

The field work and this report were the responsibility of James R. Jones, Sanitary Engineer, U. S. Bureau of Reclamation. The cooperation and assistance given by the interagency staff of the treatment center and the consultants to the project were major contributions to the success of the studies. These personnel were:

Bruce A. Butterfield . . . . . . Engineer, Department of Water Resources
James F. Arthur . . . . . . Biologist, Environmental Protection Agency
Robert G. Seals . . . . Chemist, Environmental Protection Agency
William L. Baxter . . . . . . Technician, Department of Water Resources
Dennis L. Salisbury . . . . . Technician, Department of Water Resources
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Dr. William J. Oswald . . . . University of California, Berkeley
Dr. Clarence G. Golueke . . . . . . University of California, Berkeley

SECTION VI

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SECTION VII

PUBLICATIONS

SAN JOAQUIN PROJECT, FIREBAUGH, CALIFORNIA

1968

"Is Treatment of Agricultural Waste Water Possible?"
Louis A. Beck and Percy P. St. Amant, Jr. Presented at Fourth International Water Quality Symposium, San Francisco, California. August 14, 1968; published in the proceedings of the meeting.

1969

"Biological Denitrification of Wastewaters by Addition of Organic Materials"
Perry L. McCarty, Louis A. Beck, and Percy P. St. Amant, Jr. Presented at the 24th Annual Purdue Industrial Waste Conference, Purdue University, Lafayette, Indiana. May 6, 1969.

"Comparison of Nitrate Removal Methods"
Louis A. Beck, Percy P. St. Amant, Jr., and Thomas A. Tamblyn. Presented at Water Pollution Control Federation Meeting, Dallas, Texas. October 9, 1969.

"Effect of Surface/Volume Relationship, CO_2 Addition, Aeration, and Mixing on Nitrate Utilization by _Scenedesmus_ Cultures in Subsurface Agricultural Waste Waters"
Randall L. Brown and James F. Arthur. Proceedings of the Eutrophication-Biostimulation Assessment Workshop, Berkeley, California. June 19-21, 1969.

"Nitrate Removal Studies at the Interagency Agricultural Waste Water Treatment Center, Firebaugh, California"
Percy P. St. Amant, Jr., and Louis A. Beck. Presented at 1969 Conference, California Water Pollution Control Association, Anaheim, California, and published in the proceedings of the meeting. May 9, 1969.

"Research on Methods of Removing Excess Plant Nutrients from Water"
Percy P. St. Amant, Jr., and Louis A. Beck. Presented at 158th National Meeting and Chemical Exposition, American Chemical Society, New York, New York. September 8, 1969.

"The Anaerobic Filter for the Denitrification of Agricultural Subsurface Drainage"
T. A. Tamblyn and B. R. Sword. Presented at the 24th Purdue Industrial Waste Conference, Lafayette, Indiana. May 5-8, 1969.

1969

"Nutrients in Agricultural Tile Drainage"
W. H. Pierce, L. A. Beck and L. R. Glandon. Presented at the 1969 Winter Meeting of the American Society of Agricultural Engineers, Chicago, Illinois. December 9-12, 1969.

"Treatment of High Nitrate Waters"
Percy P. St. Amant, Jr., and Perry L. McCarty. Presented at Annual Conference, American Water Works Association, San Diego California. May 21, 1969. American Water Works Association Journal. Vol. 61. No. 12. December 1969. pp. 659-662.

The following papers were presented at the National Fall Meeting of the American Geophysical Union, Hydrology Section, San Francisco, California. December 15-18, 1969. They are published in Collected Papers Regarding Nitrates in Agricultural Waste Water. USDI, FWQA, #13030 ELY December 1969.

"The Effects of Nitrogen Removal on the Algal Growth Potential of San Joaquin Valley Agricultural Tile Drainage Effluents"
Randall L. Brown, Richard C. Bain, Jr., and Milton G. Tunzi.

"Harvesting of Algae Grown in Agricultural Wastewaters"
Bruce A. Butterfield and James R. Jones.

"Monitoring Nutrients and Pesticides in Subsurface Agricultural Drainage"
Lawrence R. Glandon, Jr., and Louis A. Beck.

"Combined Nutrient Removal and Transport System for Tile Drainage from the San Joaquin Valley"
Joel Goldman, James F. Arthur, William J. Oswald, and Louis A. Beck.

"Desalination of Irrigation Return Waters"
Bryan R. Sword

"Bacterial Denitrification of Agricultural Tile Drainage"
Thomas A. Tamblyn, Perry L. McCarty and Percy P. St. Amant.

"Algal Nutrient Responses in Agricultural Wastewater"
James F. Arthur, Randall L. Brown, Bruce A. Butterfield, Joel C. Goldman.

1 Accession Number

W

2 Subject Field & Group

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SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 Organization

Water Quality Office
Environmental Protection Agency
Washington, D.C.

6 Title

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10 Author(s)

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23 Descriptors (Starred First)

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25 Identifiers (Starred First)

*San Joaquin Valley, California, Bacterial Denitrification, Anaerobic Filters, Anaerobic Ponds

27 Abstract

Operational criteria, design and operations costs for a treatment facility to remove nitrogen from agricultural tile drainage in the San Joaquin Valley were further investigated during 1970 at the Interagency Agricultural Wastewater Treatment Center near Firebaugh, California. The year-long study period is identified as Phase II. Based on projected nitrate-nitrogen concentrations for valley tile drainage water, the research in this phase extended earlier Phase I studies on the feasibility of bacterial denitrification by filters and covered ponds. The anaerobic filter with 1-inch rounded aggregate was capable of reducing influent nitrate-nitrogen from 30 mg/l to 2 mg/l at water temperatures from 12° to 16°C at a 6-hour detention time, and from 15 mg/l to 2 mg/l at water temperatures of 20° to 24°C at 1-hour detention time. Long-term operation of filters resulted in accumulation of bacterial mass which caused the deterioration of the hydraulic regime and nitrogen removal efficiencies. Air scour accompanied or followed by flushing with water was capable of controlling the bacterial mass. The consumptive ratio, a method to quantify the organic carbon source needed for anaerobic bacterial process, was affected by temperature and influent nitrogen concentration and was found to vary between approximately 1.2 and 2.4. The anaerobic covered pond reduced influent nitrate-nitrogen from 30 mg/l to 2 mg/l at water temperatures of 12° to 16°C with a 60-day detention time and from 15 mg/l to 2 mg/l at 20° to 2-°C with a 10-day detention time.

This report is submitted in partial fulfillment of Project No. 13030 ELY under the sponsorship of the Environmental Protection Agency

Abstractor: J. R. Jones

Institution: Environmental Protection Agency

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